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A Generic Autonomous Clustering-Based Heterogeneous Waveband Switching Architecture in WDM Networks

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Abstract: Heterogeneous waveband switching (HeteroWBS) in WDM networks reduces the network operational costs. We propose an autonomous clustering-based HeteroWBS architecture to support the design of efficient HeteroWBS algorithms under dynamic traffic requests in such a network.

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1. Introduction

Waveband switching (WBS) is an efficient solution, which reduces the WDM network operational costs (opex) and the size of the optical components by transmitting a small group of specific wavelengths as a single bundle along a waveband-route [1][2][3]. However, upgrading the existing optical switching architecture requires time and money [4]. It is expected that a heterogeneous waveband switching (HeteroWBS) architecture would be desirable, where some nodes can support WBS functions and the others cannot. As all previous works assume homogeneous WBS networks, the performance study of HeteroWBS networks has never been carried out.

We address the WBS problem in HeteroWBS networks under dynamic traffic requests, which should be provisioned through either wavelength-routes (lightpaths) or waveband-routes. We cluster the HeteroWBS network into multiple autonomous groups (AGs). Based on the autonomous clustering architecture, three HeteroWBS algorithms adopting different routing algorithms are proposed, which are the autonomous heterogeneous waveband switching (AS-WBS) algorithm, the autonomous source-limited heterogeneous waveband switching (AS-S-WBS) algorithm, and the shortest-path-based heterogeneous waveband switching (SH-WBS) algorithm. Finally, simulation results show that the SH-WBS algorithm outperforms the other two and the HeteroWBS algorithms can achieve optimal performance compared with the algorithm without WBS.

2. Problem Statement and Connection Management

By adding waveband-to-wavelength (de)multiplexers, fiber-to-band (de)multiplexers, and a waveband crossconnect fabric, an optical cross-connect (OXC) is capable of waveband switching, grouping, and disaggregating [5]. Such an OXC is denoted as a multi-granular optical cross-connect (MGOXC) and is shown in [2]. In a HeteroWBS network, there are MGOXC nodes and ordinary OXC nodes. A candidate path may traverse a waveband-route and thus can be classified into the following five categories. A **B-B-Path** is shown in Fig. 1(a), where the call goes through an end-to-end waveband-route [2][5]. A **B-L-Path** is shown in Fig. 1(b), where the waveband-route is originated from the source node and terminated at an intermediate MGOXC node. An **L-B-Path** is illustrated in Fig. 1(d), where the waveband-route is originated from an intermediate MGOXC node and terminated at the destination node. An **L-B-L-Path** is illustrated in Fig. 1(e), where the waveband-route is originated from an intermediate MGOXC node and terminated at another intermediate MGOXC node. Finally, An **L-L-Path** refers to a lightpath from source to destination as illustrated in Fig. 1(c). We restrict a call to be routed through at most one intermediate waveband-route. The reason is that if the path goes through multiple intermediate waveband-routes, the length of the path becomes unnecessarily long. It heavily wastes the network resources and degrades the network performance.

3. Autonomous Clustering-Based Heterogeneous Waveband Switching Architecture

We cluster the HeteroWBS network into multiple AGs. The most prominent characteristic of an AG is that only the MGOXC nodes control the waveband switching, grouping, and disaggregating functions in the AG. The rationale is that the communication among the OXCs for the WBS information is a waste and thus should be eliminated. It is important to note that the MGOXC nodes should be connected with other MGOXC nodes because that a waveband-route should consist of MGOXC nodes entirely. A call originated from an ordinary OXC node may go through a waveband-route. However, the source node has no information about the current available wavebands. It should communicate with one of the MGOXCs in the AG. Moreover, if the MGOXC were along the waveband-route, it would eliminate the waveband-route information and just provide the source node with the available route, which may or may not traverse a waveband-route, and the available wavelengths. Through this method, waveband switching is transparent to the OXCs.

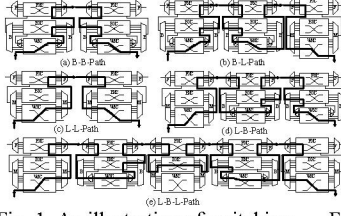


Fig. 1. An illustration of switching a call through five different categories of paths.

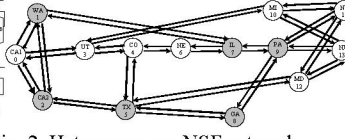


Fig. 2. Heterogeneous NSF network. Gray nodes are MGOXCs and white nodes are ordinary OXCs.

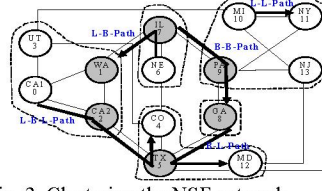


Fig. 3. Clustering the NSF network into AGs. Dash circles delimitate the clusters.

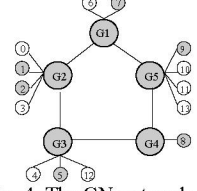


Fig. 4. The GN-network for the clustered NSF network.

Clustering of the HeteroWBS Network: The clustering of the network is ruled by the grouping strategy. First, the grouping strategy attaches MGOXCs to ordinary OXCs in the network. Given the HeteroWBS network with a set of connected MGOXCs, an ordinary OXC n_c selects its attached MGOXCs according to the following steps.

1. If n_c has neighbor MGOXCs, it adds all the neighbor MGOXCs as its attached MGOXCs. Otherwise, continue.
2. If n_c can reach multiple MGOXCs that are two hops away, it picks the one with the smallest distance or weight as its attached MGOXC. Otherwise, continue.
3. If n_c can reach MGOXCs through at least three hops, it will not be assigned with any attached MGOXC. In other words, the call originating for n_c will always be accommodated through an *L-L-Path*.

An OXC is only attached to MGOXCs that are one-hop or two-hops away. This can increase the possibility of provisioning calls through waveband-routes and reduce the possibility of wasting network resources in routing calls through long paths along intermediate waveband-routes. After determining the attached MGOXC(s) for each ordinary OXC, the AGs can be determined as follows.

1. If the ordinary OXC nodes n_{i1}, \dots, n_{ij} have the same attached MGOXC b_k and b_k is the only attached MGOXC for all of them, the ordinary nodes n_{i1}, \dots, n_{ij} , and the MGOXC b_k are clustered into an AG $\{n_{i1}, \dots, n_{ij}, b_k\}$.
2. Assume that an ordinary OXC node n_i has only one attached MGOXC b_{j1} and b_{j1} is one of the attached MGOXC in an AG $\{n_{k1}, \dots, n_{kx}, b_{j1}, \dots, b_{jy}\}$. If n_i is at most two-hops away from all of the attached MGOXCs b_{j1}, \dots, b_{jy} in the group, add n_i into the AG. Otherwise, n_i and b_{j1} are clustered into a separate AG.
3. If there is no attached MGOXC for an ordinary OXC n_i , it is clustered into a separate AG.

The clustering process continues until there is no change for all the AGs in the network. Enlarging the clusters can encourage the adoption of *L-L-Paths* with only one or two hops. Fig. 5 illustrates the clustering of the heterogeneous NSF network shown in Fig. 4. After the clustering process, the network assumes an autonomous clustering-based heterogeneous waveband switching (AS-HeteroWBS) architecture.

Heterogeneous Waveband Switching Algorithm Design: Three HeteroWBS algorithms are proposed, which adopt the first-fit waveband assignment and first-fit wavelength assignment [2][6]. The HeteroWBS algorithms provision a call upon its arrival dynamically.

The AS-WBS algorithm: It accommodates calls according to the following three principles.

1. A *B-B-Path*, *B-L-Path*, *L-B-Path* or *L-B-L-Path* is preferred to the *L-L-Path* along the same route. In other words, a waveband-route is more preferable than a wavelength-route.
2. An *L-L-Path* (L_i) across AGs for a call is preferred if the other paths are at least two-hops longer than L_i . For example, if a call $\langle UT_3, CO_4 \rangle$ arrives, the *L-L-Path* across AGs along route $UT_3 \rightarrow CO_4$ is preferred.
3. The path with the smallest hop count within an AG is preferred.

The AS-S-WBS algorithm: When a call arrives at an OXC to another OXC in a different AG, the OXC delivers the call to the shortest attached MGOXC in the AG. After the MGOXC receives the call, it searches for a shortest-path to the destination with a waveband-route along it. It also searches for the shortest path from the source node to the MGOXC and combines the routes. The wavelength assignment, waveband assignment, and the setting up of a new waveband-route are the same as the AS-WBS algorithm.

The SH-WBS algorithm: We construct a smaller group-node network (GN-network) from the AS-HeteroWBS architecture by considering each AG as a single node. There are two types of nodes in the GN-network. One is with MGOXC nodes in its AG. The other is without any MGOXC node in its AG. The connectivity of a node in the GN-network is determined by the connectivities between the MGOXC nodes in the AG and the MGOXC nodes in other AGs. If the AG contains only one OXC node, the nodal connectivity is determined by the OXC node. After the GN-network is constructed, the nodes in the AG of the AS-HeteroWBS network are connected to the corresponding node in the GN-network. The GN-network for the heterogeneous NSF network is shown in Fig. 4. When a call arrives dynamically, the SH-WBS algorithm searches for the shortest path between the two nodes in the GN-network. It then expands the real route in the original network. The SH-WBS algorithm adopts the shortest path algorithm to search for the route among the AGs. The wavelength assignment, waveband assignment, and the setting up of a new waveband-route are the same as the AS-WBS algorithm.

5. Simulation of Heterogeneous WBS Networks

We study the HeteroWBS network performance in terms of call blocking probability and cost savings under various configurations. The cost savings of the HeteroWBS algorithms are the savings of the utilized ports multiplied by the weighted cost associated with a port. We assume that a WBS port has a weight of 0.2 and a wavelength-switching port has a weight of 1.0 [1]. We employ the NSF HeteroWBS network as shown in Fig. 2. The percentage of MGOXC's is 43%. The AS-HeteroWBS network architecture is shown in Fig. 3. The GN-network is shown in Fig. 4. Poisson traffic is generated and uniformly distributed among the network nodes. The call holding time is exponential. The network load (L) in terms of Erlang can then be calculated. *SH-RWA* illustrates the results obtained by the **RWA algorithm** adopting the shortest-path routing and the first-fit wavelength assignment without WBS. Each result is obtained by simulating 100,000,000 calls.

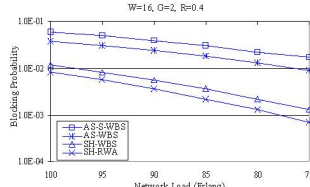


Fig. 5. Call blocking probability changes with L .

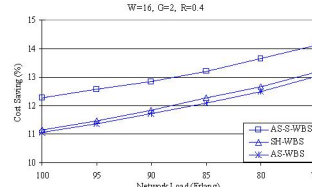


Fig. 6. Cost savings change with L .

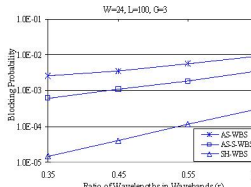


Fig. 7. Call blocking probability changes with r .

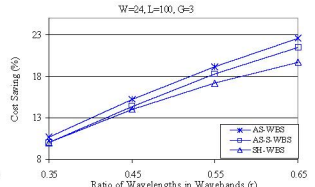


Fig. 8. Cost savings change with r .

Fig. 5 and Fig. 6 compare the algorithms under different network traffic loads (L). As can be seen, the SH-WBS algorithm can achieve better performance than the other two HeteroWBS algorithms in terms of call blocking probability. Moreover, the results of the SH-WBS algorithm are very close to the RWA algorithm. In addition, all the results show that the blocking probability decreases as the network traffic load decreases. By restricting the adoption of the shortest-path routing only, the SH-WBS algorithm consumes fewer resources than the AS-S-WBS and the AS-WBS algorithms. On the other hand, the AS-S-WBS algorithms can achieve higher cost saving ratio than the SH-WBS algorithm. This is reasonable as the AS-S-WBS and the AS-WBS algorithms try to utilize WBS as much as possible for a call. Moreover, the results show that the cost saving ratio increases as the traffic load decreases. The reason is that as the traffic load decreases, the ratio of successfully provisioned calls increases.

Fig. 7 and Fig. 8 compare the algorithms when the ratio of wavelengths in wavebands (r) changes. Again, the SH-WBS algorithm can achieve lower blocking probability and the AS-S-WBS and the AS-WBS algorithms can achieve higher cost savings. Moreover, the blocking probability slightly increases as the ratio r increases. The higher the ratio r is, the higher cost saving ratio can be obtained. This is because as r increases the number of wavebands along a fiber link. Moreover, as r increases, the performance gap between the SH-WBS algorithms and the AS-WBS and the AS-S-WBS algorithms in cost saving ratio becomes larger.

5. Conclusion

We investigated the dynamic waveband switching (WBS) problem in a heterogeneous WBS (HeteroWBS) network. To screen the WBS information from the ordinary OXC nodes, we employ a clustering algorithm to combine a specific set of OXC's and MGOXC's into an autonomous group (AG), where the MGOXC's are responsible for all the WBS functions in the AG. Three HeteroWBS algorithms were proposed based on the autonomous clustering-based architecture, namely the AS-WBS, the AS-S-WBS, and the SH-WBS algorithms. Simulations illustrated that the SH-WBS algorithm outperforms the other two and the HeteroWBS architecture is effective in improving the WDM network performance.

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